INFILTRATION FLUX DISTRIBUTIONS IN UNSATURATED ROCKS

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RESEARCH OBJECTIVES

The hydrology of unsaturated fractured rocks has received considerable attention over the past two decades. Another category of unsaturated rocks includes talus deposits in mountainous terrain and mine waste rock piles; their hydrology has received little attention. As water percolates through unsaturated rocks, do seepage paths remain uniformly distributed, converge in a manner analogous to river networks, or obey some other principle? This study was aimed at (1) determining whether well-constrained unsaturated flow distributions exist in unconsolidated rock, (2) developing a model consistent with experiments, and (3) identifying similarities between unsaturated flow in unconsolidated rock and in fractured rock.

APPROACHES

Infiltration experiments have been conducted on three different rock types (diabase, sandstone, serpentinite), with rock sizes ranging from 30 mm to 200 mm, and system scales ranging from 1 to 30 rock layers. Water was uniformly applied over the upper surface of the rock packs at various flow rates (all less than 10^{-5} that of the scale-predicted saturated hydraulic conductivity), and spatial distributions of steady state outflow were recorded in arrays of graduated cylinders placed under the lowermost rock layer (Figure 1c). Various flow-path models were developed during the course of this study, allowing individual flow-path trajectories to randomly move downward through successive underlying nearest-neighbor cells.

ACCOMPLISHMENTS

Although individual experiments yielded different spatial distributions of fluxes, we found that probability distributions of fluxes were remarkably similar. Fluxes stabilize into a geometric (exponential) distribution that keeps about half of the system depleted of flow, retains a small fraction of high flow regions, and has a scale equal to the characteristic rock size (Figure 1d). The depth-evolution of the measured flux probability distribution was predicted by modifying a statistical mechanical model, showing that the most probable (maximum entropy) macroscopic distribution of flow paths is equivalent to the Boltzmann distribution.

SIGNIFICANCE OF FINDINGS

These results are important because they have predictive value with respect to probability distributions of fluxes. The geometric distribution of fluxes is expected to be directly applicable to fluxes within talus and waste-rock deposits. Key similarities between infiltration in rock deposits and fractured rock include effectively random downward trajectories (constrained by rock geometry and gravity), balancing of flowpath merging and splitting, and flow occurring at rates many orders of magnitude lower than saturated hydraulic conductivities. These similarities indicate that our results could apply to percolation in fractured rock formations. A better understanding of infiltration path distributions will improve our ability to predict the natural biogeochemical reactive transport rates in unsaturated rocks, as well as help constrain predictions of contaminant migration to underlying groundwaters.
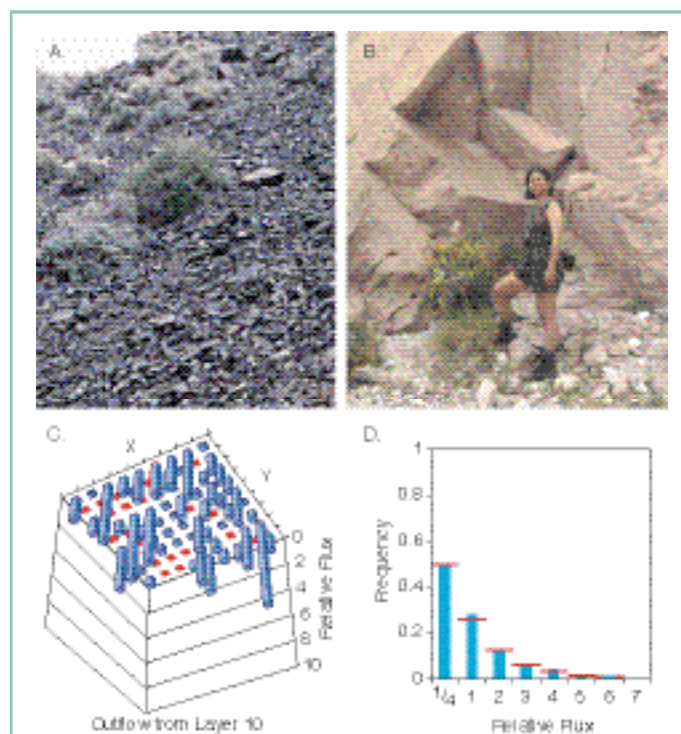

Figure 1A. Talus rock deposit (White Mountains, California); B. Fractured rock (Owens River Gorge, California); C. Spatial distribution of outflow from a rock pack experiment (10 layers); D. Probability distribution of outflow fluxes from a 10-layer rock pack, compared with a geometric distribution model (horizontal red lines).

RELATED PUBLICATION

Tokunaga, T.K., K.R. Olson, and J. Wan, Infiltration flux distributions in unsaturated rock deposits and their potential implications for fractured rock formations. Geophys. Res. Lett. 32, L05404, doi:10.1029/2004GL022203, 2005. Berkeley Lab Report LBNL-57399.

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